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(54) **PROCESS VESSEL INSULATION MONITORING**

FOREIGN PATENT DOCUMENTS

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CN	203349859 U	12/2013
CN	104061443 A	9/2014
CN	105651856 A	6/2016

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OTHER PUBLICATIONS

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Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority from International Application No. PCT/US2019/037701, dated Sep. 13, 2019.

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(57) **ABSTRACT**

An industrial process vessel insulation monitoring system for monitoring an insulated section of a process vessel containing a process material includes one or more condition sensors and a controller. The condition sensors are configured to sense at least one environmental condition, such as temperature, humidity, moisture level, and/or chemical composition, and generate condition outputs that are indicative of the corresponding sensed condition. The controller is configured to detect at least one section condition relating to the insulated section based on the condition output, and generate condition information relating to the at least one detected section condition. Examples of the section conditions include a thermal resistance of an insulation of the insulated section, damage or degradation to an insulation of the insulated section, corrosion of the process vessel at the insulated section, conditions that promote corrosion of the process vessel, and moisture intrusion to the insulation.

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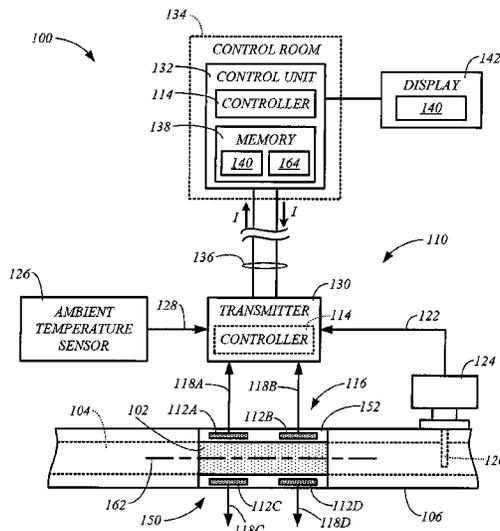
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(56) **References Cited**

U.S. PATENT DOCUMENTS

2003/0079553 A1 5/2003 Cain et al.
2012/0056634 A1 3/2012 Bohon et al.
(Continued)

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(56) **References Cited**

U.S. PATENT DOCUMENTS

2014/0161151 A1* 6/2014 Proctor G01K 1/143
374/147
2014/0305524 A1 10/2014 Heizer et al.
2017/0045412 A1 2/2017 Yunker et al.

OTHER PUBLICATIONS

Communication Pursuant to Rules 161(1) and 162 from European Patent Application No. 1974503.6, dated Feb. 19, 2021.
Office Action from Chinese Patent Application No. 201811579563.5, dated Apr. 6, 2021.

* cited by examiner

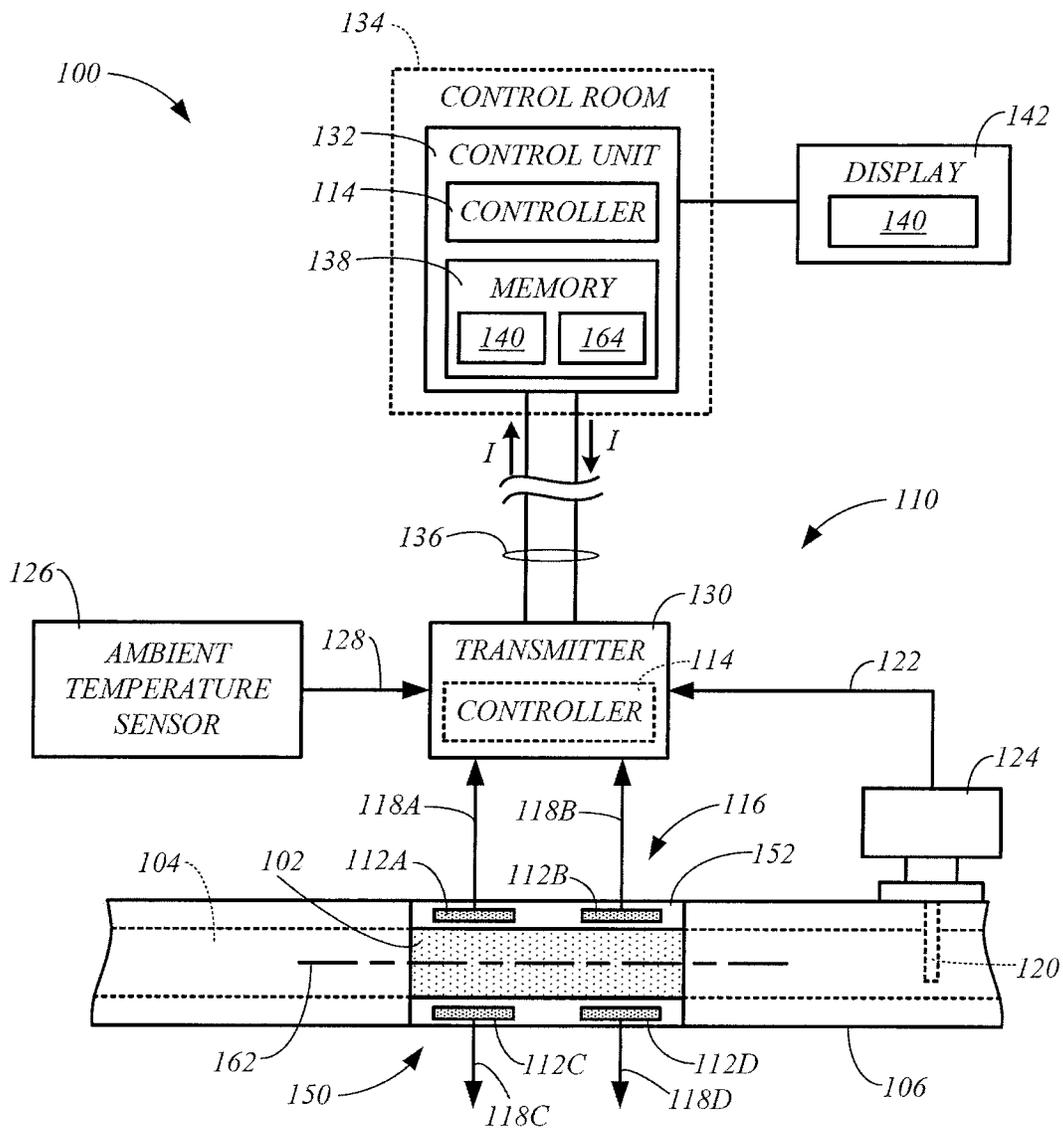


FIG. 1

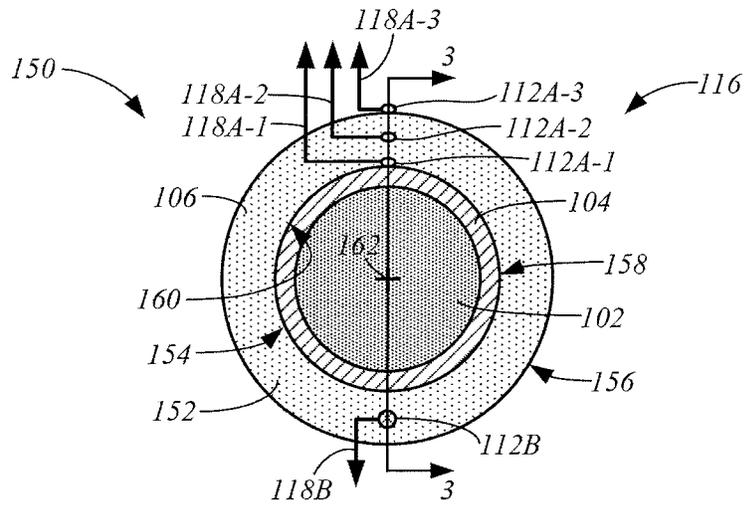


FIG. 2

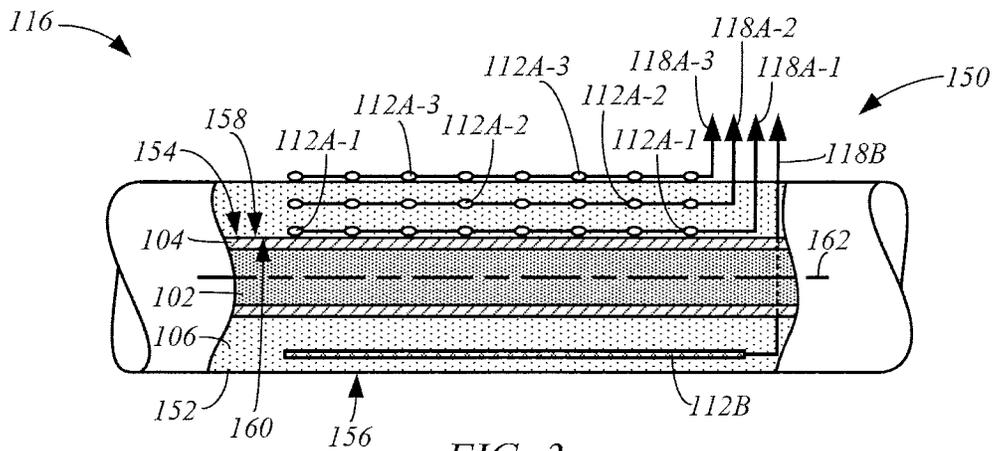


FIG. 3

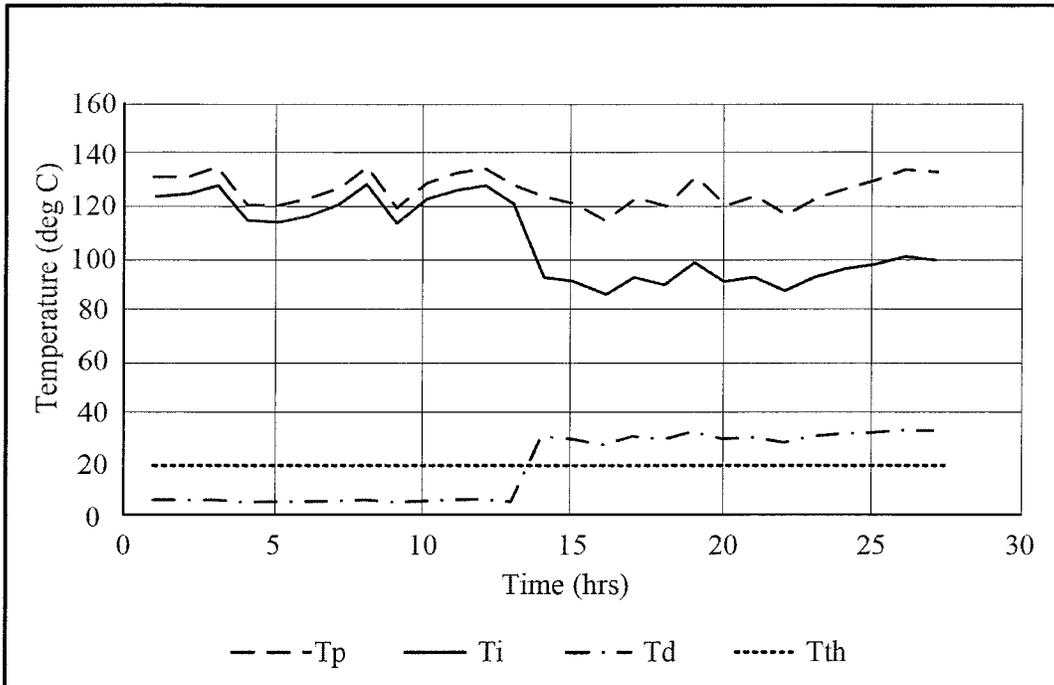


FIG. 4

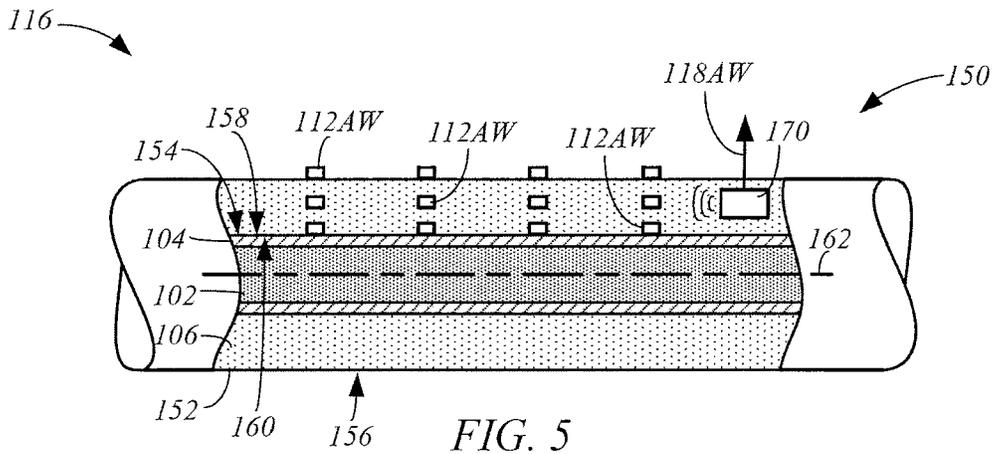


FIG. 5

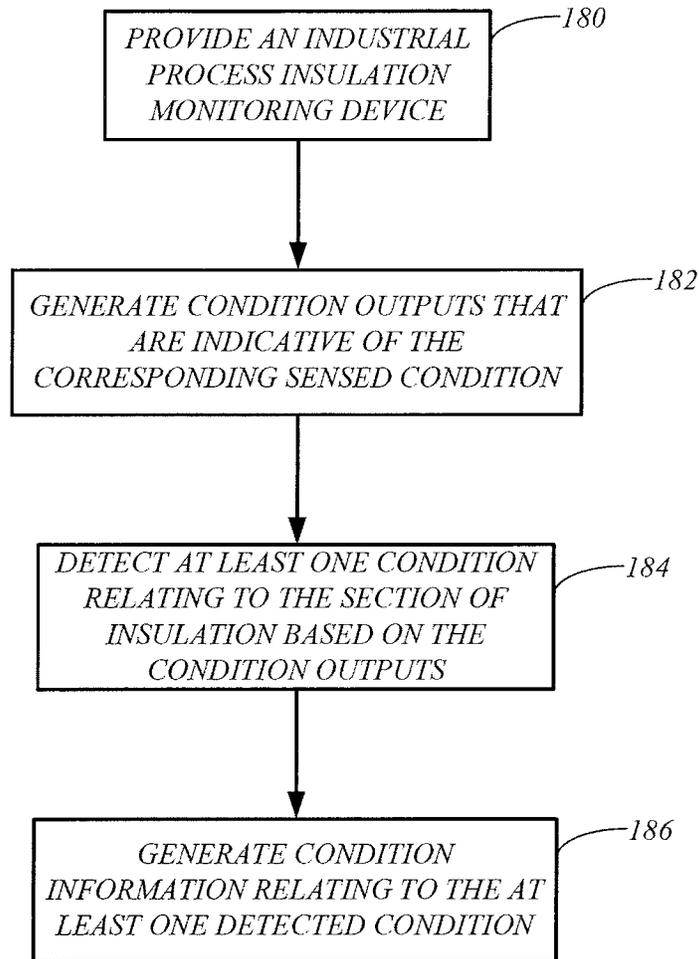


FIG. 6

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PROCESS VESSEL INSULATION MONITORING

BACKGROUND

Embodiments of the present disclosure relate to industrial process control systems for industrial plants. More specifically, embodiments of the present disclosure relate to monitoring process vessel thermal insulation health.

In industrial settings, control systems are used to monitor and control inventories of industrial and chemical processes, and the like. Thermal insulation systems are critical assets within typical industrial plants, such as oil refineries, chemical plants and food and beverage production facilities, for example. Such systems typically utilize an insulative material that surrounds a process vessel (e.g., a pipe, a conduit, or a tank) and reduces heat transfer between the process material within the process vessel and the surrounding environment. Insulation systems that are compromised due to physical damage or environmental influences can lead to reduced operating efficiency and product quality.

SUMMARY

Embodiments of the present disclosure are directed to an industrial process vessel insulation monitoring system for monitoring an insulated section of a process vessel containing a process material, an industrial process vessel insulation monitoring device, and a method of monitoring an insulated process vessel. One embodiment of the system includes one or more condition sensors and a controller. The one or more condition sensors are configured to sense at least one environmental condition at or within the insulated section of the process vessel, such as temperature, humidity, moisture level, and/or chemical composition. Each of the one or more condition sensors is configured to generate a condition output that is indicative of the corresponding sensed condition. The controller is configured to detect at least one section condition relating to the insulated section based on the condition output, and generate condition information relating to the at least one detected section condition. Examples of the section conditions include a thermal resistance of an insulation of the insulated section, damage or degradation to an insulation of the insulated section, corrosion of the process vessel at the insulated section, conditions that promote corrosion of the process vessel, and moisture intrusion to the insulation.

One embodiment of the industrial process vessel insulation monitoring device includes a section of insulation, and a plurality of condition sensors that are attached to the insulation. The plurality of condition sensors is configured to sense at least one environmental condition at or within the section of insulation. Examples of the environmental condition include temperature, humidity, moisture level and/or chemical composition. Each of the plurality of condition sensors is configured to generate condition outputs that are indicative of the corresponding sensed condition.

In one embodiment of the method of monitoring an insulative process vessel, the above-described insulation monitoring device is provided. Condition outputs using the plurality of condition sensors are generated using the plurality of condition sensors. Each condition output indicates the corresponding sensed condition. At least one section condition relating to the section of insulation and the process vessel is detected based on the condition outputs using a controller. Examples of the section conditions include a thermal resistance of an insulation of the insulated section,

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damage or degradation to an insulation of the insulated section, corrosion of the process vessel at the insulated section, conditions that promote corrosion of the process vessel, and moisture intrusion to the insulation. Condition information relating to the at least one detected section condition is generated using the controller.

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter. The claimed subject matter is not limited to implementations that solve any or all disadvantages noted in the Background.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified diagram of an exemplary industrial process measurement or control system **100**, in accordance with embodiments of the present disclosure.

FIG. 2 is a simplified cross-sectional view of an exemplary insulating monitoring device, in accordance with embodiments of the present disclosure.

FIG. 3 is a simplified cross-sectional view of the device of FIG. 2 taken generally along line **3-3**, in accordance with embodiments of the present disclosure.

FIG. 4 is a chart including plots of exemplary measured interface and process temperatures over time, a difference between the interface and process temperatures, and a threshold temperature difference, in accordance with embodiments of the present disclosure.

FIG. 5 is a simplified side cross-sectional view of an exemplary insulation monitoring device, in accordance with embodiments of the present disclosure.

FIG. 6 is a flowchart illustrating an exemplary method of monitoring an insulated process vessel using an insulation monitoring device, in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

Embodiments of the present disclosure are described more fully hereinafter with reference to the accompanying drawings. Elements that are identified using the same or similar reference characters refer to the same or similar elements. The various embodiments of the present disclosure may be embodied in many different forms and should not be construed as limited to the particular embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the present disclosure to those skilled in the art.

FIG. 1 is a simplified diagram of exemplary industrial process measurement or control system **100**, in accordance with embodiments of the present disclosure. The system **100** may be used in the processing of a process material **102**, such as a fluid (i.e., liquid or gas), a solid (i.e., granular or powdered material), a slurry, etc., to transform the material from a less valuable state into more valuable and useful products, such as petroleum, chemicals, paper, food, etc. For example, an oil refinery performs industrial processes that can process crude oil into gasoline, fuel oil, and other petrochemicals.

The process material **102** may be contained or transported through a process vessel **104**, such as a tank, a pipe, or another process vessel. The process vessel **104** may be

insulated using a suitable thermal insulation **106**, as shown in FIG. 1. As discussed above, the insulation **106** may degrade over time, which can affect the thermal resistance (i.e., R-value) of the insulation **106**. Additionally, the deterioration of the insulation **106** can affect the health of the vessel **104** itself. For example, the deterioration of the insulation **106** can lead to the presence of moisture at the interface between the exterior surface of the process vessel **104** and the interior of the insulation **106**, which can lead to a corrosion under insulation (CUI) condition at the exterior surface of the vessel **104**.

Embodiments of the present disclosure are directed to a process vessel insulation monitoring system **110** that is configured to monitor and/or detect one or more conditions relating to the process vessel **104** and/or the insulation **106**, such as the thermal resistance of the insulation **106**, CUI conditions, moisture intrusion, and/or other conditions relating to the vessel **104** and/or the insulation **106**.

Some embodiments of the monitoring system **110** include one or more condition sensors **112**, generally referred to as **112**, and a controller **114**. In some embodiments, the sensors **112** of the monitoring system **110** include one or more sensors for sensing conditions at an insulated section **116** relating to the insulation **106** and the process vessel **104**, and generating one or more outputs, generally referred to as **118**, that indicate the sensed conditions.

In some embodiments, the sensors **112** may include one or more temperature sensors **112A** having a temperature output **118A**, one or more moisture level sensors **112B** having a moisture level output **118B**, one or more chemical composition sensors **112C** having a chemical composition output **118C**, one or more humidity sensors **112D** having a humidity output, and/or sensors **112** configured to monitor other environmental conditions of the insulated section **116**. Thus, the one or more condition sensors **112** may be configured to sense temperature, moisture, humidity, chemical composition, and/or another environmental condition relating to the insulated section **116** of the vessel **104**, and generate one or more condition outputs **118** indicating the sensed conditions. The controller **114** detects the one or more conditions relating to the process vessel insulation **106** based on the one or more sensed environmental conditions indicated by the condition outputs **118**.

The temperature sensor or sensors **112A** may be configured to monitor temperatures associated with the insulated section **116** of the process vessel **104**, and generate temperature outputs **118A** relating to the sensed temperatures. As discussed below in greater detail, the temperature sensor outputs **118A** may be used by the controller **114** to measure a thermal resistance of the insulation **106**, detect missing, damaged, or degraded insulation **106**, and detect conditions which may indicate, or lead to a CUI condition, for example. The one or more temperature sensors **112A** may utilize any suitable temperature sensor, such as a resistance temperature detector, a negative temperature coefficient thermistor, a thermocouple, a semiconductor-based temperature sensor, or other suitable temperature sensor.

The moisture level sensor or sensors **112B** are configured to monitor a moisture level associated with the insulated section **116** of the process vessel **104**, and generate moisture level outputs **118B** relating to the detected moisture levels. The moisture level outputs **118B** may be used by the controller **114** to detect conditions that may lead to a CUI condition, damage to the insulation **106**, and other conditions of the insulated section **116**. The one or more moisture level sensors **112B** may include a moisture detection cable or other suitable moisture sensor.

The chemical composition sensor or sensors **112C** may be used to detect the presence of corrosive chemicals, such as acids, alkalis, and/or salts, and/or corrosion by-products, such as metal oxides, and generate chemical composition outputs **118C** that indicate the detection of such corrosion by-products. Thus, the chemical composition outputs **118C** may be used by the controller **114** to detect a CUI condition, for example. The one or more chemical composition sensors **112C** may take on any suitable form. Exemplary sensors **112C** include pH, oxygen reduction potential, electrical conductivity, and insulation resistance sensors.

The humidity sensor or sensors **112D** may be used to sense a humidity level, and generate humidity level outputs **118D** that indicate the sensed humidity level. Thus, the humidity level outputs **118D** may be used by the controller **114** to detect conditions that may promote a CUI condition, for example. The one or more humidity sensors **112D** may take on any suitable form.

The monitoring system **110** may also include a process temperature sensor **120**, which is configured to detect a temperature of the process material **102**, and generate a process temperature output **122** that is indicative of the sensed temperature. The process temperature sensor **120** may be a component of a field device **124** that is coupled to the process, as shown in FIG. 1. The process temperature output **122** may be used by the controller **114** to, for example, detect the thermal resistance of the insulation and other conditions of the insulated section **116**.

The monitoring system **110** may also include an ambient temperature sensor **126** that is configured to detect a temperature of the environment at, or near, the insulated section **116** of the process vessel **104**, and generate an ambient temperature output **128** based on the sensed temperature. The controller **114** may use the ambient temperature output **128** in the assessment or detection of conditions of the insulated section **116**, such as the thermal resistance of the insulation **106** or damage to the insulation **106**, for example.

In some embodiments, the monitoring system **110** includes a transmitter **130** that is configured to receive the output signals (e.g., condition outputs **118**, process temperature output **122**, and ambient temperature output **128**) from the one or more sensors, and transmit section information, which is based on the output signals, to a control unit **132**. The control unit **132** may be remotely located from the transmitter in a control room **134**, for example, as shown in FIG. 1. The control unit **132** may be communicatively coupled to the transmitter **130** over a suitable physical communication link, such as a two-wire control loop **136**, or a wireless communication link. Communications between the control unit **132** and the transmitter **130** may be performed over the control loop **136** in accordance with conventional analog and/or digital communication protocols.

In some embodiments, the control loop **136** includes a 4-20 milliamp control loop, in which the one or more sensor outputs (e.g., condition outputs **118**, process temperature output **122**, and ambient temperature output **128**) may be represented by a level of a loop current **I** flowing through the control loop **136**. Exemplary digital communication protocols include the modulation of digital signals onto the analog current level of the two-wire control loop **136**, such as in accordance with the HART® communication standard. Other purely digital techniques may also be employed including FieldBus and Profibus communication protocols.

The transmitter **130** may also be configured to communicate wirelessly with the control unit **132** using a conventional wireless communication protocol. For example, the transmitter **130** may be configured to implement a wireless

mesh network protocol, such as WirelessHART® (IEC 62591) or ISA 100.11a (IEC 62734), or another wireless communication protocol, such as WiFi, LoRa, Sigfox, BLE, or any other suitable protocol.

Power may be supplied to the transmitter **130** from any suitable power source. For example, the transmitter may be wholly powered by the current **I** flowing through the control loop **136**. A suitable power supply may also be utilized to power the transmitter **130**, such as an internal or an external battery. An electrical power generator (e.g., solar panel, a wind power generator, etc.) may also be used to power the transmitter **130** and/or charge an internal or external battery source for the transmitter **130**.

The controller **114** may represent components of the transmitter and/or the control unit, as shown in FIG. **1**. The controller **114** includes one or more processors (i.e., microprocessor, central processing unit, etc.) that perform one or more functions described herein in response to the execution of instructions, which may be stored locally in non-transitory computer readable media or memory of the control unit, such as memory **138**, or memory of the transmitter, for example. In some embodiments, the processors of the controller **114** are components of one or more computer-based systems, such as the control unit **132**. The controller **114** may include one or more control circuits, microprocessor-based engine control systems, one or more programmable hardware components, such as a field programmable gate array (FPGA), that are used to control components of the monitoring system **110** and/or perform one or more functions described herein. The controller **114** may also represent other conventional industrial process transmitter or control unit circuitry.

In some embodiments, the controller **114** detects one or more conditions relating to the insulated section **116** of the process vessel **104** based on one or more of the condition outputs **118** from the sensors **112**. Additionally, the controller **114** is configured to generate condition information **140** relating to the detected condition or conditions of the section **116** of the process vessel **104**.

When the controller **114** is entirely or partially contained within the transmitter **130**, the transmitter **130** may communicate the condition information **140** to the control unit **132** as the transmitted section information mentioned above. Alternatively, the section information transmitted by the transmitter **130** relating to the condition outputs **118** may be used by the controller **114** of the control unit **132** to produce the condition information **140**.

In some embodiments, the condition information **140** generally includes information regarding each detected condition, such as, for example, an identification of the detected condition, values of the sensed conditions relating to the detected condition (e.g., temperature measurements, humidity measurements, moisture level measurements, chemical composition measurements, etc.), and/or other information. The condition information **140** may be logged in memory of the system **110**, as indicated in FIG. **1**, or communicated to a desired data storage system or computing device, for example. The controller **114** may issue a notification relating to the condition information **140** including displaying of the condition information **140** on a display, such as the display **142** of the control unit **132**, or another display, triggering an alarm, and/or providing another type of notification.

Some embodiments of the industrial process vessel insulation monitoring system **110** include an industrial process vessel insulation monitoring device **150** that generally includes a section **152** of the insulation **106** and one or more of the condition sensors **112** described above, which are

attached to the insulation section **152**, as shown in FIG. **1**. Exemplary embodiments of the insulation monitoring device **150** will be described with reference to FIGS. **2** and **3**. FIG. **2** is a simplified cross-sectional view of an exemplary insulating monitoring device **150**, and FIG. **3** is a simplified cross-sectional view of the device **150** of FIG. **2** taken generally along line **3-3**, in accordance with embodiments of the present disclosure.

In some embodiments, the insulation section **152** may comprise a sleeve of insulation **106** that completely surrounds the process vessel **104** (e.g., pipe), as shown in FIG. **2**. For example, the insulation section **152** may be configured to wrap around the process vessel **104**. Alternatively, the insulation section **152** may form only a portion of the insulation **106** that insulates the process vessel **104**.

The device **150** may include one or more of the temperature sensors **112A** at various locations between an exterior surface **154** of the process vessel **104** and an exterior surface **156** of the insulation section **152**. For example, the device **150** may include one or more interface temperature sensors **112A-1** at an interface **158** between the insulation section **152** and the exterior surface **154** of the process vessel **104**, one or more embedded temperature sensors **112A-2** within the insulation section **152**, and/or one or more exterior temperature sensors **112A-3** at the exterior surface **156** of the insulation section **152**, as shown in FIGS. **2** and **3**. The interface temperature sensors **112A-1** may be attached to an interior surface **160** of the insulation section **152**, or positioned between the interior surface **160** of the insulation section **152** and the exterior surface **154** of the process vessel **104** when the insulation section **152** is installed on the process vessel **104**. The exterior temperature sensors **112A-3** may be attached on the exterior surface **156** of the insulation section **152** using any suitable technique, or embedded in the exterior surface **156** of the insulation section **152**. Accordingly, in some embodiments, the one or more temperature sensors **112A** includes at least two temperature sensors that are positioned at different radial distances from a longitudinal axis **162** of the process vessel **104** or the insulation section **152**, as shown in FIG. **2**.

In some embodiments, the interface temperature sensors **112A-1** are used to detect temperatures that promote a CUI condition. For example, when the interface temperature indicated by the output **118A-1** of the interface temperature sensors **112A-1** is within a temperature range that promotes corrosion of the process vessel **104**, the controller **114** may generate condition information relating to the detection, such as, for example, a notification indicating the presence, or the potential development of, a CUI condition.

The interface temperature sensors **112A-1** may also be used to detect damage or degradation to the insulation section **152**. In some embodiments, the controller **114** compares the temperature indicated by the output **118A-1** to an anticipated temperature or temperature range that is expected to be detected by the interface temperature sensors **112A-1**, and detects damage to the insulation section **152** when the difference between the detected interface temperature and the anticipated interface temperature or temperature range exceeds a corresponding threshold value **164**, which may be stored in the memory **138** (FIG. **1**) of the control unit **132**, for example. The controller **114** may generate condition information **140** relating to the detected damage or degradation to the insulation section **152**, which may include a notification of the degraded condition of the insulation section **152**. In some embodiments, the controller **114** sets the anticipated interface temperature based on the process

temperature sensed by the process temperature sensor **120**, and/or the ambient temperature sensed by the ambient temperature sensor **126**.

When the insulation section **152** is substantially undamaged, the difference between the interface temperature and the process temperature is small, but when the insulation section **152** becomes damaged, its insulative performance drops and the difference between the interface temperature and the process temperature increases. This is generally illustrated in the chart of FIG. 4, which includes plots of exemplary measured interface temperatures (T_i) and process temperatures (T_p) over time, a difference (T_d) between the interface and process temperatures, and a threshold temperature difference value (T_{th}), in accordance with embodiments of the present disclosure. The threshold temperature difference value, which may be stored as one of the threshold values **164** (FIG. 1), is used to evaluate the condition of the insulation section **152**. In some embodiments, the threshold temperature difference value is selected to indicate when the insulation section **152** is no longer providing a desired level of thermal insulation. In the example illustrated by the chart in FIG. 4, the temperature difference between the interface temperature and the process temperature transitions from below the threshold temperature difference to above the threshold temperature difference at around the 14-hour mark, thereby indicating that the insulation section **152** may have become damaged around that time and requires repair or replacement. Thus, the controller **114** detects this damage or degraded condition of the insulation section **152** based on the difference between the interface temperature and the process temperature, and generates condition information **140** (e.g., a notification) in response to this detection of the condition.

As mentioned above, this monitoring of the interface temperature relative to the process temperature may include a compensation for ambient temperature conditions, on which the anticipated interface temperature has some dependency. Specifically, the threshold temperature difference may be adjusted based on a difference between the ambient temperature indicated by the ambient temperature sensor **126** and the process temperature indicated by the process temperature sensor **120**, which are shown in FIG. 1. For example, when the difference between the ambient temperature and the process temperature is low, the threshold temperature difference value may be reduced due to the anticipated lower heat transfer between the process vessel **104** and the surrounding environment, and when the difference between the ambient temperature and the process temperature is high, the threshold temperature difference value may be increased due to the anticipated higher heat transfer between the process vessel **104** and the surrounding environment. Thus, the threshold temperature difference value may be dynamically adjusted by the controller **114** using the ambient temperature sensed or measured by the sensor **126**.

In some embodiments, the one or more temperature sensors **112** are used by the controller **114** to measure the direct heat flow through the insulation section **152**, and/or the thermal resistance (R-value) of the insulation section **152**. For example, the controller **114** may use the difference between the interface temperature output **118A-1** by the one or more interface temperature sensors **112A-1**, and the embedded temperature output **118A-2** from the one or more embedded temperature sensors **112A-2** and/or the exterior temperature output **118A-3** by the one or more exterior temperature sensors **112A-3** to calculate a heat flow through the insulated section **152**, and/or a thermal resistance for the

insulation section **152** using conventional techniques. The controller **114** may compensate these measurements of the heat transfer or thermal resistance based on the ambient temperature output **128** from the ambient temperature sensor **126** (FIG. 1). The controller **114** generates condition information **140**, which may indicate the measured heat flow through the insulation section **152** and/or the thermal resistance of the insulation section **152**.

In some embodiments, the controller **114** respectively compares the calculated heat flow and/or thermal resistance to a corresponding threshold heat flow or thermal resistance values, which may be stored in the memory **138** as one of the threshold values **164**, to establish whether the insulation section **152** is providing a desired level of insulation. The condition information **140** generated by the controller **114** may indicate whether the heat flow through the insulation section **152** and/or the thermal resistance of the insulation section **152** meets a desired standard based on the threshold values.

Some embodiments of the monitoring device **150** include one or more moisture sensors **112B** which, as mentioned above, may include a moisture detection cable, as illustrated in FIGS. 2 and 3. The moisture detection sensor **112B** may be embedded within the insulation **106** and generate the moisture level output **118B** relating to a detected moisture level. This allows the controller **114** to directly monitor for a moisture intrusion to the insulated section **152**, which can lead to both degradation of the insulation section **152** and a CUI condition. In some embodiments, the controller **114** compares the detected moisture level to a threshold moisture level value, which may be stored as one of the threshold values **164** (FIG. 1). The controller **114** may generate condition information **140** based on the moisture level output **118B**, and/or the comparison between the detected moisture level and the threshold moisture level value, which may include the detected moisture level and other related information. Additionally, when the detected moisture level exceeds the moisture level threshold value, the condition information **140** may include a notice of potential damage or degradation to the insulation section **152**, and/or a notice indicating that conditions exist that may lead to a CUI condition, for example.

When the monitoring device **150** includes one or more of the chemical composition sensors **112C**, the controller **114** may use the chemical compositions indicated by the corresponding outputs **118C** to detect a CUI condition, or conditions that may lead to a CUI condition. The condition information **140** generated by the controller may include information regarding the detected chemical compositions, such as an identification of the detected compositions (e.g., iron oxides), a concentration of the detected compositions, and other information. In some embodiments, the controller **114** is configured to compare a concentration of a detected composition to a threshold concentration value, which may be stored as one of the threshold values **164** (FIG. 1). When the detected concentration level exceeds the threshold concentration value, the condition information **140** may include a notice of potential damage or degradation to the process vessel **104**, a notice of potential damage or degradation to the insulation section **152**, and/or a notice indicating that a CUI condition exists or may exist, for example.

As discussed above, some embodiments of the monitoring device **150** include one or more humidity sensors **112D**. The one or more humidity sensors **112D** generate the humidity level output **118D** relating to a detected humidity level, which can be used by the controller **114** to directly monitor for conditions that can lead to a CUI condition. In some

embodiments, the controller **114** compares the detected humidity level to a threshold humidity level value, which may be stored as one of the threshold values **164** (FIG. **1**). The controller **114** may generate condition information **140** based on the humidity level output **118D**, and/or the comparison between the detected humidity level and the threshold humidity level value, which may include the detected humidity. Additionally, when the detected humidity level exceeds the humidity level threshold value, the condition information **140** may include a notice of potential damage or degradation to the insulation section **152**, and/or a notice indicating that conditions exist that may lead to a CUI condition, for example.

As mentioned above, the condition sensors **112** may utilize a plurality of the sensors **112** to sense a particular condition, such as temperature. Thus, for example, the temperature sensors **112A** may include a plurality of temperature sensors **112A** that are each used to perform discrete temperature measurements at various locations. For example, the interface temperature sensors **112A-1**, the embedded temperature sensors **112A-2**, and/or the exterior temperature sensors **112A-3** may each include a plurality of temperature sensors that are displaced from each other along the longitudinal axis **162** of the process vessel **104** or the insulation section **152**, as shown in FIG. **3**.

The temperature sensed by each of the individual temperature sensors **112A** may be processed by the controller to determine an average temperature measurement. Thus, the temperatures sensed by the interface temperature sensors **112A-1** may be processed to determine an average interface temperature, the temperatures sensed by the embedded temperature sensors **112A-2** may be processed to determine an average embedded temperature, and the temperatures sensed by the exterior temperature sensors **112A-3** may be processed to determine an average exterior temperature. The controller **114** may use one or more of these average temperatures to detect the one or more conditions relating to the insulation section **152**. The controller may similarly determine average measurements for other environmental conditions (e.g., humidity, moisture level, chemical composition, etc.) by averaging the measurements from multiple condition sensors **112**.

The condition sensors **112** may take on any suitable form and may include wired connections to the transmitter **130** to convey the generated condition outputs. One exemplary alternative to this arrangement includes the use of passive surface acoustic wave sensors **112AW** in combination with a radio frequency exciter and reader **170**, as generally shown in FIG. **5**, which is a simplified side cross-sectional view of an exemplary insulation monitoring device **150**, in accordance with embodiments of the present disclosure. The surface acoustic wave sensors **112AW** each receive energy from the radio frequency exciter and reader **170**, which may be powered by the transmitter **130**, and responsively generate a radio frequency signal that has a phase angle change or another detectable radio frequency characteristic change, such as frequency or amplitude, that is a function of the measured parameter. The exciter and reader **170** receives the signals from the acoustic wave sensors **112AW** and delivers the condition outputs **118AW** to the transmitter **130** (FIG. **1**). Accordingly, the one or more temperature sensors **112A**, moisture level sensors **112B**, chemical composition sensors **112C** and humidity sensors **112D**, may be replaced with suitable surface acoustic wave sensors **112AW** to thereby eliminate the need for wired connections to each of the sensors. Alternatively, the embedded measurement devices

could take the form of passive RFID sensors that are energized and read by an RFID reader that may be powered by the transmitter **130**.

Additional embodiments of the present disclosure are directed to a method of monitoring an insulated process vessel **104** using the insulation monitoring device **150**. FIG. **6** is a flowchart illustrating an example of the method in accordance with embodiments of the present disclosure. At **180** of the method, an industrial process insulation monitoring device **150**, which is formed in accordance with one or more embodiments described above, is provided. In some embodiments, the device **150** includes an insulation section **152** that is attached to the process vessel **104**, and a plurality of condition sensors **112** that are attached to the insulation section **152**. The condition sensors **112** are each configured to sense at least one environmental condition at or within the insulation section **152**, such as temperature, humidity, moisture level and/or chemical composition, for example. The condition sensors **112** are configured to generate condition outputs **118** that are indicative of the corresponding sensed condition, such as a temperature output **118A**, the moisture level output **118B**, a chemical composition output **118C**, and/or a humidity output **118D**, as shown in FIG. **1**.

At **182** of the method, condition outputs **118** are generated using the plurality of condition sensors **112** that are indicative of the corresponding sensed condition. At least one condition relating to the insulation section **152** is then detected, at step **184** based on the condition outputs **118**, using the controller **114**. For example, the controller **114** may detect a thermal resistance of the insulation section **152**, damage (i.e., degradation) to the insulation section **152**, corrosion of the process vessel **104** or conditions conducive to corrosion of the process vessel **104**, and/or moisture intrusion of the insulation section **152**, based on the condition outputs from the condition sensors **112**, as discussed above.

At **186** of the method, condition information **140** is generated relating to the at least one detected section condition using the controller **114**. As discussed above, the condition information **140** may identify the detected condition, include the sensed parameters relating to the detected condition, notifications regarding the detected condition, and/or other information relating to the detected condition. In some embodiments of the method, the condition information **140** is communicated to a user, such as through a display **142** of a control unit **132** (FIG. **1**). The condition information **140** may also include notifications, such as an alarm, that notify the user of the detected condition.

Although the embodiments of the present disclosure have been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the present disclosure.

What is claimed is:

1. An industrial process vessel insulation monitoring system for monitoring an insulated section of a process vessel containing a process material, the system comprising:
 - one or more condition sensors configured to sense at least one environmental condition at or within the insulated section consisting of temperature, humidity, moisture level and chemical composition, wherein each of the one or more condition sensors is configured to generate a condition output that is indicative of the corresponding sensed condition; and
 - a controller configured to detect at least one section condition relating to the insulated section including a thermal resistance of an insulation of the insulated

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section, based on the condition output, and generate condition information relating to the at least one detected section condition.

2. The system of claim 1, wherein the system includes a transmitter configured to receive the condition outputs and transmit section information, which is based on the condition outputs, to an external control unit.

3. The system of claim 1, wherein the one or more condition sensors comprise a radio frequency exciter and at least one surface acoustic wave sensor.

4. The system of claim 1, wherein:

the one or more condition sensors includes a moisture sensor configured to sense the moisture level and generate a moisture output indicative of the moisture level;

the controller is configured to detect the at least one section condition based on the moisture output; and the at least one section condition includes a moisture intrusion to the insulation.

5. The system of claim 4, wherein the moisture sensor includes a moisture detection cable attached to the insulation.

6. The system of claim 1, wherein the one or more condition sensors includes one or more temperature sensors at a location selected from the group consisting of an interface between an exterior of the process vessel and the insulation, within the insulation and attached to an exterior surface of the insulation, each of the one or more temperature sensors configured to generate a temperature output that is indicative of the corresponding sensed temperature.

7. The system of claim 6, wherein:

the one or more temperature sensors includes at least two temperature sensors that are displaced from each other along an axis extending from an interface between the process vessel and the insulation to an external surface of the insulation; and

the at least one section condition includes the thermal resistance of the insulation.

8. The system of claim 6, wherein the one or more temperature sensors are each selected from the group consisting of a resistance temperature detector, a negative temperature coefficient thermistor, a thermocouple, and a semiconductor-based temperature sensor.

9. The system of claim 6, wherein:

the system comprises an ambient temperature sensor configured to generate an ambient temperature output indicative of an ambient temperature that is external to the insulation; and

the controller is configured to detect the at least one section condition based on the ambient temperature output.

10. The system of claim 6, wherein the one or more temperature sensors comprises a plurality of temperature sensors that are displaced from each other along a longitudinal axis of the process vessel.

11. The system of claim 10, wherein the controller detects the at least one section condition based on an average of the temperatures indicated by the temperature outputs of the plurality of temperature sensors.

12. The system of claim 6, wherein:

the one or more temperature sensors includes at least one interface temperature sensor at an interface between the process vessel and the insulation, the at least one interface temperature sensor configured to generate an interface temperature output that is indicative of a temperature of the interface; and

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the controller is configured to detect the at least one section condition based on the interface temperature output.

13. The system of claim 12, wherein:

the at least one interface temperature sensor includes a plurality of interface temperature sensors that are displaced from each other along a longitudinal axis of the process vessel;

the one or more temperature sensors include a plurality of exterior temperature sensors that are attached to an exterior surface of the insulation, displaced from each other along the longitudinal axis, and configured to generate an exterior temperature output that is indicative of the temperature of the exterior surface of the insulation; and

the system includes a moisture sensor attached to the insulation and configured to sense a moisture level and generate a moisture output indicative of the moisture level;

the controller is configured to detect the at least one section condition based on the interface temperature output, the exterior temperature output and the moisture output; and

the at least one section condition comprises a moisture intrusion condition.

14. The system of claim 12, wherein:

the system includes a process temperature sensor configured to generate a process temperature output that is indicative of a temperature of a process material contained in the process vessel; and

the controller is configured to detect the at least one section condition based on the process temperature output.

15. The system of claim 14, wherein the controller is configured to detect the at least one section condition based on a comparison of a threshold value to a difference between the temperatures of the process material and the interface.

16. An industrial process vessel insulation monitoring device comprising:

a section of insulation;

a plurality of condition sensors attached to the insulation and configured to sense at least one environmental condition at or within the section of insulation consisting of temperature, humidity, moisture level and chemical composition, wherein each of the plurality of condition sensors is configured to generate condition outputs that are indicative of the corresponding sensed condition; and

wherein the plurality of condition sensors includes one or more temperature sensors attached to an interior surface of the section of insulation and an exterior surface of the section of insulation, each of the one or more temperature sensors configured to generate a temperature output that is indicative of the corresponding sensed temperature.

17. The device of claim 16, wherein the one or more temperature sensors comprises a plurality of temperature sensors attached to the interior surface and a plurality of temperature sensors attached to the exterior surface.

18. The device of claim 17, wherein the plurality of condition sensors includes a moisture sensor configured to sense a moisture level and generate a moisture output indicative of the sensed moisture level.

19. A method of monitoring an insulated process vessel comprising:

providing an industrial process insulation monitoring device comprising:

a section of insulation attached to the process vessel;
and
a plurality of condition sensors attached to the insula-
tion and configured to sense at least one environ- 5
mental condition at or within the section of insula-
tion consisting of a temperature, a humidity, a
moisture level and a chemical composition, wherein
each of the plurality of condition sensors is config-
ured to generate condition outputs that are indicative
of the corresponding sensed condition; 10
generating condition outputs using the plurality of con-
dition sensors, each condition output indicative of the
corresponding sensed condition;
detecting at least one section condition relating to the
section of insulation including a thermal resistance of 15
the section of insulation, based on the condition out-
puts, using a controller; and
generating condition information relating to the at least
one detected section condition using the controller.

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